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(54) ELECTRONIC SCANNING ANTENNA WITH DIODE PHASE SHIFTERS  
INCORPORATING A CUT-OFF DEVICE

We, THOMSON-CSF, a French Body Corporate, of 173, Boulevard Haussmann, 75008 PARIS – FRANCE, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which is to be performed, to be particularly described in and by the following statement:–

The present invention relates to a diode phase-shifting device for an electronic scanning antenna and, more especially in such a device, a so called diode cut-off device which is used at the instant at which the diode or diodes are switched from their conducting to their non-conducting state. The said cut-off device is a complement to the conventional means already known and used.

Electronic scanning antennas comprise a primary source and a network of phase-shifters associated with radiating means. Each phase-shifter of the type considered in the present invention is formed by a microwave line coupled to normal PIN diodes which, as a function of their conducting or non-conducting state, enable reactances to be introduced which vary the phase angle. The switching between the non-conducting and conducting state of the phase-shifting diodes occurs quickly. On the other hand, the reverse switching from the conducting to the non-conducting state does not occur instantaneously. At the instant of switching, each diode begins to act as a short-circuit in which the reverse current increases and then its cuts off. At this instant, when the polarity of the voltage applied to the junction of each PIN diode is reversed, the current in the diode decreases rapidly and then reverses suddenly. This current is due to the movement of the minority carriers which had previously been stored during the period of direct conduction at the junction level.

The charges stored are a function of the lifetime of the minority carriers and of the direct current before switching. The flow of these charges is ensured by the cut-off means which provide a reverse current that produces the elimination of the charge carriers.

It must be done quickly so that the time required for switching is as short as possible. This condition is indispensable if it is desired to use the phase-shifter mentioned above for the

antennas of short range and hence high repetition rate radars or for antennas of long range radars in which it is useful to be able to change the aim of the antenna during a repetition period.

However the speed of the change of aim is a function of the speed of switching of the phase-shifting diodes which is itself related to the intensity of the current supplied by the cut-off devices.

In accordance with known practice, the cut-off devices which deliver a reverse current as soon as it is desired to cut off the diodes are formed by a high voltage source combined with a high resistance. The high voltage supply, which is bulky, is significant. Much power is supplied and the thermal dissipation is high. As a result, there are large temperature variations in the diode cut-off device and the minority carriers in the phase-shifting diodes, which have a life that increases with temperature, are eliminated slowly and hence slow down the switching speed.

An object of the invention is to provide a PIN diode cut-off device which has not got the disadvantages cited above and which is free of the limits indicated. Thus, in accordance with the invention, the phase-shifting diode or diodes, at the instant they are switched to the non-conducting state, are fed in succession with current coming from a low voltage source and then with a current from a high voltage source. The high current intended to ensure rapid switching to cut-off is supplied with a considerable reduction of the power required under previous arrangements. This cut-off device reduces the thermal dissipation at the level of the circuits controlling the electronic scanning antenna.

In accordance with the invention, there is provided a diode phase-shifting device for an electronic scanning antenna comprising means for controlling the conducting and non-conducting states of at least one phase-shifting diode and including a high voltage source coupled to said at least one diode through a resistor, a switch inserted between the high voltage source and said at least one diode, a low voltage source also coupled to said diode through a resistor and control means for controlling said

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switch to close the latter when the voltage at an electrode of said at least one diode exceeds a given threshold.

5 The invention will be described in greater detail and by way of example with reference to the accompanying drawings, in which:

— FIG. 1. is a diagrammatic view of one embodiment of a cut-off device for a phase-shifting diode and,

10 — FIG. 2 is a detailed diagram of the cut-off device.

Referring to FIG. 1 the cut-off device 40, which is acting on a phase-shifting diode 1 of the PIN type opens up automatically when the 15 control of the conducting current in diode 1 is cut-off, this being determined by phase control device 2. The cut-off device contains a high voltage current generator 10 formed by a high voltage source 3 in series with resistor R1 which is connected through a switch I1 to the cathode of diode 1. It also contains a low voltage current generator 20 comprising a low voltage source 6 in series with resistor R2 which is connected via the diode 4 to point P2 at the cathode of diode 1.

20 The resistor 2 is also connected at point P1 to one input of a comparator 5 whose other input is connected to a reference voltage source 30 and whose output controls the closing of switch I1.

25 The diode cut-off device only operates when 30 all the control modules are cut-off. Each indication of the phase-shifts required to obtain a fresh aim of the antenna may require, for example, the cutting off of all the phase-shift devices, one of which is shown as diode 1, as 35 already mentioned, and then the initiation of means to allow only those diodes to conduct which are required to set up the fresh aim of the antenna which is desired.

30 This requires the diode cut-off device to be 40 operative after a forced but-off instruction supplied by phase control device 2 during the time while the change of aim of the antenna is occurring. The forced cut-off instruction acting on diode 1 when it is conducting, causes it to 45 change from the conducting state to the cut-off state. When this change of state called "switching" occurs, diode 1, through which flows a reverse current resulting from the movement of 50 minority carriers that were previously stored during the conducting period, has a relatively low impedance. At the start of switching, switch I1 is kept open and low voltage generator 20, through 55 low voltage source 6, low value resistor R2 and diode 4, supplies a high current intended to cause the evacuation of the minority charges in diode 1.

55 The potential at point P1, and hence at point 60 P2, increases. At the end of the evacuation of the minority carriers fixed by low voltage generator 6, the potential at P1 is such that, by comparison with reference voltage 30, the comparator 5, acts on switch I1 to close it and so controls the connection of high voltage generator 3 to diode 1. The low voltage generator then no longer feeds diode 1. Thus, the high voltage generator 65 now supplies a current which charges the

parasitic capacity in diode 1; this causes a quick rise in voltage in the diode almost to the reverse high voltage. Diode 4 is also cut-off and the low voltage generator can no longer deliver current to diode 1.

70 The forced cut-off instruction can then terminate. Normal control is authorized and, depending on the circumstances, it maintains the diode cut-off or causes the diode considered to conduct. In the case of maintained cut-off, high voltage generator 3 cannot supply an output and diode 1 remains cut off although the diode cut-off device is no longer operating. In the case when the diode is to be conducting, high voltage current generator 3 is cut off by comparator 5 opening switch I1.

75 FIG. 2 shows in more detailed fashion the circuit diagram of one embodiment of a cut-off device for a phase-shifting diode in accordance with the invention.

80 The diode cut-off device 40 contains high voltage current generator 10, low voltage current generator 20, reference voltage source 30 and comparator 5. Cut-off device 40 is associated in the example described with phase-shifting diode 1 whose anode is connected to ground and whose cathode is coupled through resistor R4 to the cut-off or phase control 2 formed by a reference voltage generator which triggers the cut-off of the diode considered by delivering a positive voltage during the time that the change of antenna aim is taking place.

85 High voltage current generator 10 contains a high voltage source 3 which may be, for example, of the order of 150 V, connected through the resistor R1 to the collector of a transistor T3, of the PNP type for example, the said transistor T3 being coupled to a transistor T2 also of the PNP type. The two transistors T2 and T3 form a Darlington pair which, in operation, acts as a single transistor whose input impedance is high. The collector of transistor T3 is connected to a ground through a capacitor C. The emitter of transistor T3 is connected at A to diode 7 through a load resistor R3 of low value of the order of 10 kohms in the example described. Diode 7 is connected at E to diode 1. High voltage current generator 10 is connected through diode 4 to low voltage current generator 20 which contains low voltage supply source 6, giving about 5 volts in the example described which feeds resistor R2 of low value, i.e. of the order of 1 kohm.

90 100 Low voltage current generator 20 is connected at D to the emitter of transistor T1 which forms comparator element 5. The collector of T1 is connected at C to a high voltage source 8 through a resistor R5 of high value and also to the base of transistor T2. The base of transistor T2 is connected at B to a reference voltage generator 30 formed by a Zener diode Z whose anode is connected to ground and whose cathode is connected to a resistor R6.

105 110 115 120 125 130 The diode cut-off device is started by the forced cut-off instruction coming from voltage

generator 2. Diode 1 changes to the cut-off state on switching ; it acts as a short-circuit and, because of that, appears as a fairly low impedance. Low voltage current generator 20 supplies through low resistor R2, which is of the order of 1 kohm in the example described, a high reverse current to diode 1 which eliminates the minority carriers. The power supply is not very high. The voltage at E, A and D rises and transistor T1 is held open as long as the difference in potential between points B and D is greater than or equal to 0.6 V. At this specific instant, transistor T1 cuts off and causes the potential at point C to rise to that of high voltage source 8, which is of the order of 150 V in the example described.

Transistors T2 and T3, which were cut-off till then, conduct again. The voltage at the terminals of R1 is of the order of 150 V in the example described, diode 4 is cut off and low voltage generator 20 no longer supplies current through diode 1 whose impedance value is high. The phase-shifting diode 1 is no longer short-circuited and high voltage current generator 10 supplies the current which charges the parasite capacities of diode 1. It causes the quick rise of the voltage in diode 1 to the reverse high voltage cut-off.

Switching may, as an indication in the example described, last 30  $\mu$ s.

The operating of low voltage current generator 20 may then last 10  $\mu$ s. During the next 20  $\mu$ s, low voltage current generator 20 is inoperative and high voltage current generator 10 is operative.

In the case in which the antenna system contains  $n = 2000$  phase-shifting units of 2 bits each, each phase-shifting unit comprising 3 diodes and each diode cut-off device being associated with two phase-shifting units, it may be noted that  $\frac{n}{2}$  cut-off devices may correspond to these phase-shifting units.

A diode cut-off device for an antenna system with electronic scanning has thus been described. With a minimum of components, it enables a high current, which ensures quick switching, to be supplied to each phase-shifting diode. The cut-off device enables the action of the high voltage current generator to be delayed until the minority carriers are eliminated by the action of the low voltage current generator. It also makes possible a reduction of 3 to 5 times in the high voltage power supply.

What we claim is:-

55 1. A diode phase-shifting device for an

electronic scanning antenna comprising means for controlling the conducting and non-conducting states of at least one phase-shifting diode and including a high voltage source coupled to said at least one diode through a resistor, a switch inserted between the high voltage source and said at least one diode, a low voltage source also coupled to said at least one diode through a resistor and control means for controlling said switch to close the latter when the voltage at an electrode of said at least one diode exceeds a given threshold.

2. A diode phase-shifting device as in claim 1, wherein said control means comprises a comparator device having one input connected to a reference voltage and its other input connected to the output of the low voltage source and to an electrode of said at least one phase-shifting diode, the output from said comparator closing the said switch when the voltage at said other input of said comparator reaches the threshold set by said reference voltage.

3. A phase-shifting device as in claim 2, wherein said switch comprises two transistors connected in a Darlington pair circuit.

4. A phase-shifting device as in claim 2 or 3, comprising a further protective diode inserted between said low voltage source and said at least one phase-shifting diode.

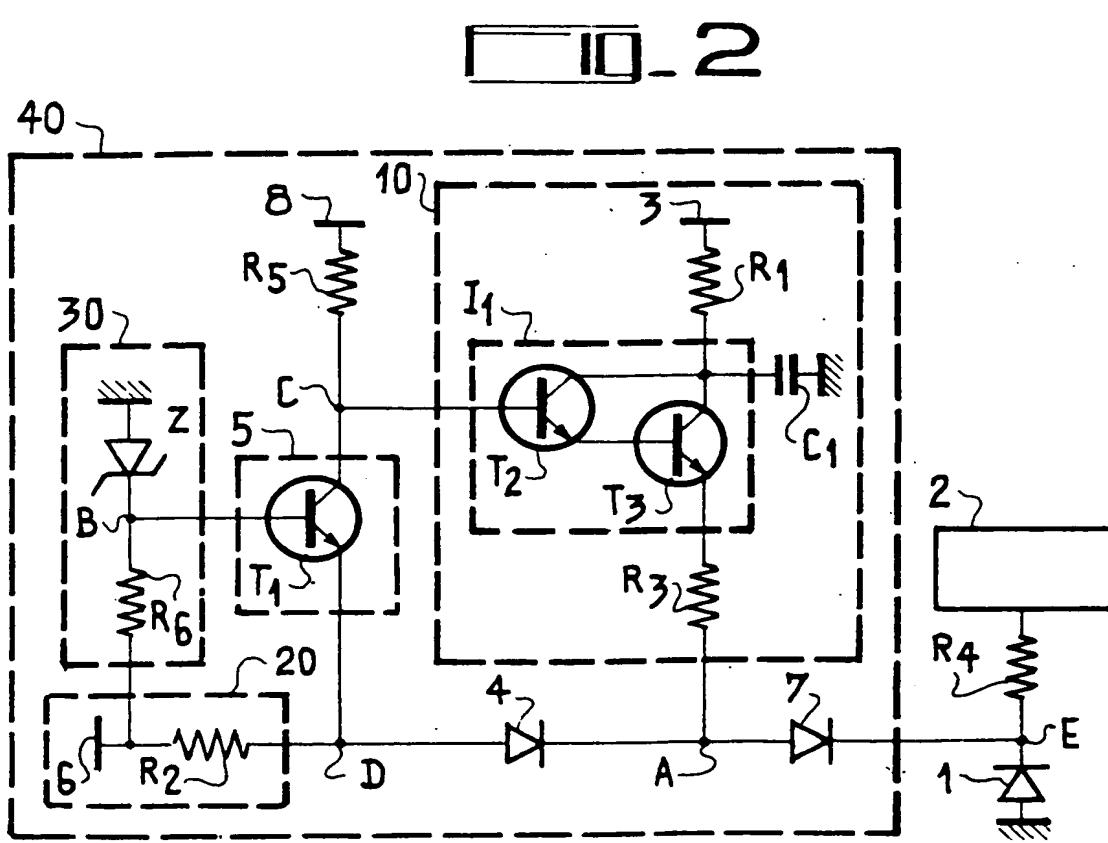
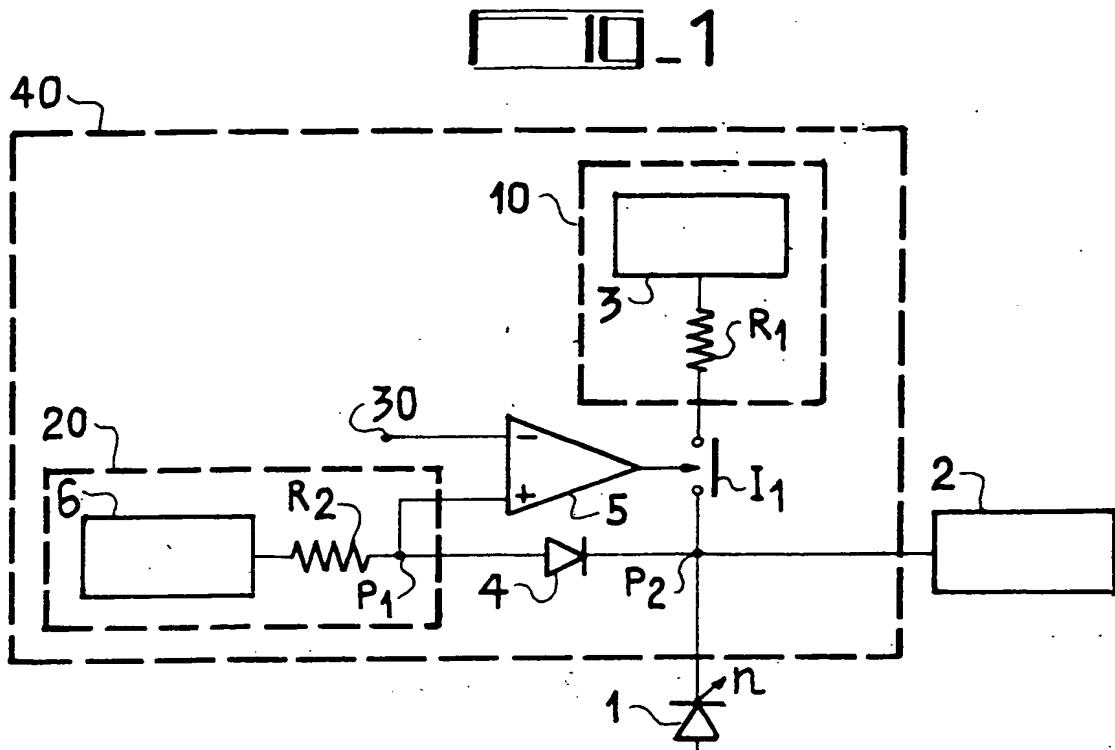
5. A diode phase-shifting device as claimed in claim 4, wherein the rapid switching of said at least one phase-shifting diode forming a phase-shifting unit of said antenna in the non-conducting direction operates successively said low voltage source supplying a current through its associated resistor and said protective diode and said high voltage source supplying a current through its associated resistor and a further diode, the switching from one source to the other being made through a said switch which operates when the voltage at an electrode of said phase-shifting diode reaches said given threshold value.

6. A diode phase-shifting device substantially as hereinbefore described with reference to the accompanying drawings.

7. An electronic scanning antenna comprising a diode phase-shifting device as claimed in any of the preceding claims.

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**ERRATUM**

Specification No. 1 605 326

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Heading (52) after HIQ before FF insert Q add UIS S2139

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